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ON THE STARTING OF SUPERSONIC NOZZLES WITH THE AID OF CYLINDRICAL DIFFUSERS

by

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ABSTRACT

(U) The efficiency of short cylindric diffusers was experimentally investigated in a supersonic wind tunnel provided with exchangeable nozzles with a conical supersonic section designed for M equals 2; 2.5; 3.0; 3.5; 4.0; and 5.0 and a half cone angle of alpha equals 8 degrees for all M numbers. The diffusor lengths varied from one to eight calibers of the nozzle exit cross sections. Compressed nitrogen was used as the working substance. A graph of the ratio of the aerodynamic stagnation pressure during startup of a nozzle with diffusers to the relative diffuser length showed the advantage of using diffusers at higher nozzle M values. A diffuser length of up to 3-4 nozzle calibers practically exhausts the possibility of decreasing the starting pressure of nozzles with calculated M values of less than 3. Diffuser lengths up to 6-7 calibers are expedient on nozzles for nearly hypersonic M values. Sufficiently long cylindrical diffusers have an efficiency of 0.75-0.85. Diagrams are presented for selecting minimum diffuser lengths in the range of M equals 2-5. The experiments revealed that the maximum rarefaction attainable with cylindrical diffusers at the nozzle exit section during discharge into a normal atmosphere is 0.04 abs. Orig. art. has: 4 figures.

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ON THE STARTING OF SUPERSONIC NOZZLES WITH THE AID OF CYLINDRICAL DIFFUSERS

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To obtain systematic data on the effectiveness of short cylindrical diffusers we performed experiments on a small-sized short-term supersonic tube. Compressed nitrogen was used as the working substance. On the tube there were exchangeable nozzles with a conical supersonic part for Mach numbers 2.0, 2.5, 3.0, 3.5, 4.0, and 5.0 with a cone half-angle $\alpha = 8^{\circ}$ for all Mach numbers.

Experiments were performed with diffusers whose length varied from one to eight diameters of the exit section of the nozzles. The results given in the article are valid for the case where the ratio of the diameter of the diffuser to the diameter of the exit section of the nozzle D_d/D_s is equal to 1.01.

The diffusers were designed from plexiglas. On the inner surface of the models before the tests a layer of mastic was applied, which made it possible to follow the shocks visually and to fix the moment of the start of the nozzle (exit of the shock beyond the edge of the nozzle) and the movement of the shock along the diffuser. The pressures in the prechamber of the tube at the nozzle edge and at a number of points along the diffuser were measured by photographing

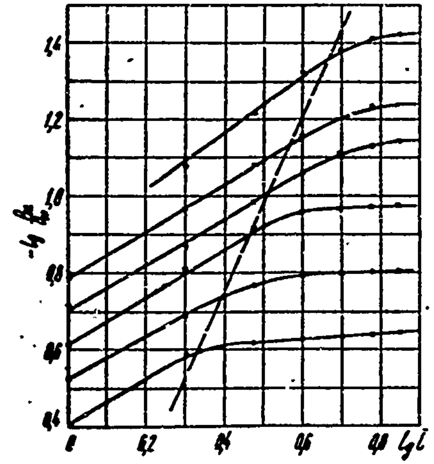

Fig. 1.

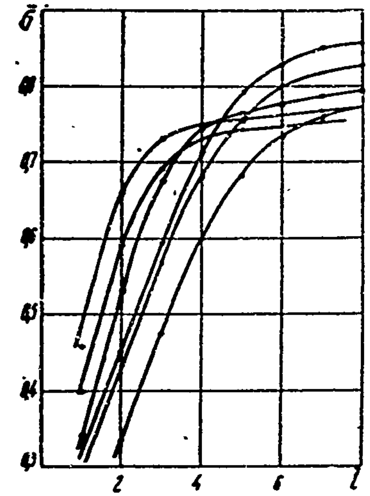

Fig. 2.

Fig. 1. Dependence of (P_{oz}/P_{or}) on $\bar{l}$:
o — M = 2; Δ — M = 2.5; □ — M = 3; ∇ — M = 3.5; × — M = 4; ● — M = 5.

Fig. 2. Dependence of the coefficient $\bar{\sigma}$ on $\bar{l}$:
o — M = 2; Δ — M = 2.5; □ — M = 3; ∇ — M = 3.5; × — M = 4; ● — M = 5.

manometers and vacuum gauges. The results of the experiments are shown in Figs. 1-4.

Figure 1 shows the dependence of the stagnation pressure P_{oz}, at which the nozzles start with the diffusers, on the relative length of the diffusers $\bar{l} = l/D_d$, where l is the length of the diffuser. For clear representation of the pressure, P_{oz} is referred to the computed pressure P_{or} necessary for starting a nozzle without the diffuser. The pressures in the external medium are assumed in both cases to be identical. The dependence is given in logarithmic coordinates. The dashed line shows the limit of effectiveness of the use of cylindrical diffusers. By limit of effectiveness we mean a straight line running

through the points in which the ratio $\lg\frac{P_{oz\ i}}{P_{or\ i}} / \lg\frac{P_{oz\ i+1}}{P_{or\ i+1}}$ amounts to no less than 0.95 with an increase in $\lg\bar{x}$ by 0.1.

From the graph we can see that the advantages of the use of diffusers are greater, the higher the Mach number of the nozzles. An increase in the length of the diffuser to three or four diameters practically exhausts the possibility of lowering the pressure of the start of the nozzles with calculated Mach numbers less than 3. For nozzles with Mach numbers close to hypersonic it is expedient to lengthen the diffusers to six or seven diameters.

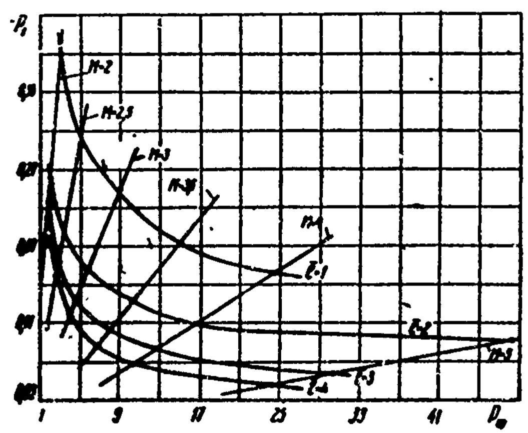

Fig. 3. Diagram for selecting the minimum diffuser lengths.

It is known that pressure recovery in a supersonic diffuser is ordinarily calculated by substituting the actual system of shocks by one normal shock.* On the graphs of Fig. 2 the stagnation pressure recovery factor obtained by us experimentally in the diffusers $\sigma_d = P_a/P_{oz}$ is referred to the recovery factor in the normal shock:

$$\sigma_{sk} = \frac{P_{02}}{P_{01}} = \frac{\left(\frac{k+1}{2} M_1^2\right)^{\frac{k}{k-1}} \left(\frac{2k}{k+1} M_1^2 - \frac{k-1}{k+1}\right)^{\frac{1}{k-1}}}{\left(1 + \frac{k-1}{2} M_1^2\right)^{\frac{k}{k-1}}}.$$

Here P_a is the pressure in the external medium and P_{01} and P_{02} are the stagnation pressures ahead of and beyond the shock. We will call the value $\bar{\sigma} = \sigma_d/\sigma_{sk}$ the diffuser efficiency. As is seen, cylindrical diffusers of sufficient length have an efficiency of the order of 0.75-0.85.

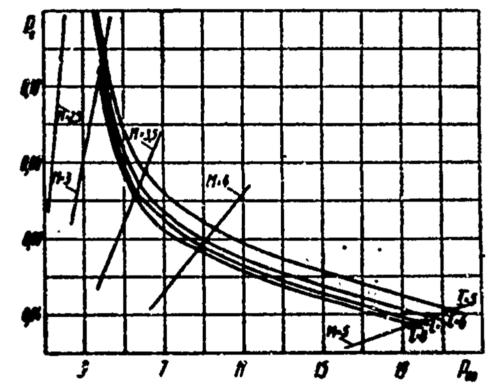

Fig. 4. Diagram for selecting minimum diffuser length.

Selection of the minimally permissible length of the diffusers in the range of Mach numbers M = 2-5 can be done from Figs. 3 and 4. We constructed, in axes P_{oz} and P_1, where P_1 is the pressure on the edge of the started nozzle, curves of the dependences $P_1 = f(P_{oz})$ with given lengths of the diffuser at different Mach numbers, to which there correspond the straight lines $\pi = P_1/P_{oz}$ = const. After we have set the calculated Mach number of the nozzle for which the diffuser is selected it is necessary to construct, through the coordinate origin (Figs. 3 and 4), a straight line at angle ϕ = arctg $\pi(M)$ to the axis of the abscissa. In Figs. 3 and 4 several such straight lines are constructed. Then, depending on whether there is given the necessary pressure of the start or the necessary expansion at the edge of the

*Fundamentals of Gas Dynamics, edited by H. Emmons, Izd-vo inostr. lit., Moscow, 1964.

nozzle, we erect a perpendicular to the axis of the abscissa or the axis of the ordinate at the point with the given value for P_{oz} or P_1 to intersection with the straight line ϕ = arctg $\pi(M)$. If the point of intersection lies between the curves $\bar{I} = i$ and $\bar{I} = i + 1$, then for finding $\bar{I}_{min}$ we can interpolate between i and i + 1 or, to guarantee the start of the nozzle, take $\bar{I}_{min} = \bar{I}_{i+1}$.

For Mach numbers up to 5 the maximum expansion at the nozzle edge, obtainable with the aid of cylindrical diffusers with outflow into normal atmosphere, as experiment shows, amounts to 0.04 atm(abs).

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